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CONTAINER FAILURE DETECTION SYSTEM

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1 September, 1962 - 28 February, 1963

A prototype system has been fabricated and tested with a model billet container. Records produced by the system during the tests indicate a high degree of capability and reliability in detecting longitudinally oriented cracks

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Basic Industry Branch
Manufacturing Technology Laboratory
Aeronautical Systems Division
Air Force Systems Command
United States Air Force



ABSTRACT-SUMMARY
Interim Technical Progress Report

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The pulse echo technique was adopted; though preliminary experiments with through transmission promised sufficient sensitivity for automated recording of flaw depth and location, further investigation utilizing the model billet container revealed effects detrimental to its successful use. Integration of the "roller skate" water coupler, scanning system and recording system was accomplished through tests conducted with the model billet container. Subsequent inspection with the system has revealed its ability to detect naturally occurring, longitudinally oriented cracks.

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FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF 33(657)-7461 from 1 September, 1962 to 28 February, 1963. This period represents the fourth report period of the project. It is published for Technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract with the General American Transportation Corporation, MRD Division, Niles, Illinois was initiated under ASD Methods and Materials Division Project 7-915, "Container Failure Detection System". It was administered under the direction of Mr. C. Cook and Mr. T. Felker of the Basic Industry Branch (ACTRB), Manufacturing Technology Laboratory, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

Mr. Marvin B. Levine of the MRD Division's Systems Engineering Group is Project Engineer. Others who cooperated in the research and preparation of the report were: Mr. B. Johnson, Group Leader, and Mr. Alfred Wiczorek, Assoc. Engineer. The project has the internal number MR 1177.

PUBLICATION REVIEW

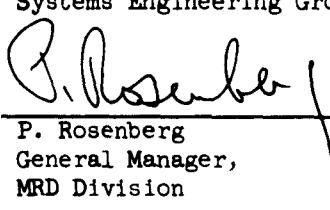
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TABLE OF CONTENTS

<u>SECTION</u>		<u>Page</u>
	NOTICES	ii
	FOREWORD	iii
1	INTRODUCTION	1
2	ULTRASONIC INSPECTION SYSTEM FOR BILLET CONTAINERS	4
	2.1 System Description	4
	2.2 System Development	13
	2.2.1 Recording and Electronics	13
	2.2.2 Coupling	18
	2.2.2.1 Liquid Coupling	19
	2.2.2.2 Wheel Search Units With Grease Couplant ...	25
	2.2.3 Crack Depth Measurements and Beam Transmission ...	29
	2.3 Evaluation with Model Billet Container	39
3	FUTURE ACTIVITY	56
	DISTRIBUTION LIST	
	ASTIA CARD	

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LIST OF ILLUSTRATIONS

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
1	Angle Beam Flaw Detection	5
2	Inspection System Diagram	5
3	System as Used with Model Billet Container	6
4	Inspection Record Format	9
5	Inspection Records of Model Billet Container	11
6	Varigate Block Diagram	15
7	Varigate Schematic	15
8	Gating Waveforms	16
9	Gap Coupler	20
10	Roller Skate Search Unit as Used in System	23
11	Roller Skate Search Unit	24
12	Metal Tire and Mold	26
13	Indications Received in Silicone Rubber Test	28
14	Test Setup for Measuring Crack Depth	30
15	Responses Obtained in Measuring Crack Depth	32
16	Parameters Used in Locating Crack Positions	40
17	Transducer-Crack Angular Separation	43
18	Record Used to Determine Synchronization	44
19	Inspection Record Depicting Crack Origin at 12 Inches from Ram End of Model Billet Container	45
20	Indications Received at Ram End of Model Billet Container	47

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LIST OF ILLUSTRATIONS (Continued)

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
21	Pulse Travel Distance Variation in Model Billet Container	49
22	Indications of Pulse Travel Distance Variation in Model Billet Container	50
23	Shear Wave Reflection Characteristics	52
24	Effect of Gate Setting on Inspection Records	54

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SECTION 1

INTRODUCTION

The intent and purpose of Contract AF 33(657)-7461 is the development of an in-press inspection system for the billet containers of the Air Force Heavy Press Program. Its primary objective is the demonstration and evaluation of a feasibility model inspection system capable of performing in-press inspection of operational billet containers. The program began with a Study Phase during which the failure history of the billet containers and the state-of-the-art of nondestructive testing were investigated. The Study Phase report, ASD Interim Report 7-915(I), was issued 15 February, 1962 and described efforts during the period 1 November, 1961 and 31 January, 1962.

The subsequent reports, ASD Interim Technical Report 7-915(II) issued 15 May, 1962 and ASD Interim Technical Report 7-915(III) issued 15 September, 1962 have reported activity during the first two periods of the second or Development and Fabrication Phase of the program which was initiated 1 March, 1962. This report similarly describes continued activity during the second phase and covers the period from 1 September, 1962 to 31 February, 1963.

The system recommended upon completion of the Study Phase proposed a hybrid, automated inspection system functioning within the bore and utilizing both ultrasonic and electromagnetic search units. Due to their inherent capabilities, ultrasonics would perform total volumetric inspection while simultaneously, eddy currents being limited in depth penetration, would inspect the bore surface for failure inception. Parallel efforts were thus pursued until it was determined through a re-examination of practices and

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discussion with ASD personnel that the ability to measure and record the actual depth of liner cracks was of equal or greater importance than determination of inception. Due to this change in program emphasis, the hybrid system yielded to exclusive ultrasonic inspection since the magnetic properties of the H12 tool steel billet containers do not permit liner crack depth determination with electromagnetic methods. However, a practical electromagnetic (eddy current) system did result and is available for other ASD or industry application.

Initial efforts in ultrasonic inspection during the Development and Fabrication Phase, as contained in the earlier reports, were directed towards implementation of and experimentation with Study Phase concepts. During this report period, a complete inspection system including a bore scanning mechanism and automatic flaw recording was fabricated. The system was tested within the bore of the failed billet container described in Interim Technical Report 7-915 (III), and based on the results of this testing, warrants extensive investigation by virtue of its ability to repeatably detect naturally occurring cracks. This capability indicates that the system may be extended to a universal design for all operational assemblies and subsequently, in-press inspection.

Contained within this report are the results of tests conducted with the system and the results of definitive experiments conducted as part of system development. Included are unmodified plan view recordings made by the system in inspecting the model billet container and a description of the method used to interpret them. These are typical of the type which will be produced

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through system usage on operational containers. Additionally, problem areas and efforts in high temperature ultrasonic inspection are discussed together with the proposed use of a silicone rubber, wheel search unit.

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SECTION 2

ULTRASONIC INSPECTION SYSTEM FOR BILLET CONTAINERS

2.1 System Description

This section briefly describes the inspection system that has evolved as a result of this ASD program, and includes test results and system performance information obtained during this report period. The development details are discussed in Section 2.2.

The present system is based on the angle beam, pulse echo method of ultrasonic inspection and utilizes the reflective properties of shrink fits within billet container assemblies to detect longitudinally oriented, radial cracks originating at the bore surface. The ultrasonic shear wave pulse in the liner enters at an angle of sixty degrees relative to the bore surface normal, is reflected to the bore surface by an internal shrink fit, and if a crack is present, is reflected back to the transducer in the manner illustrated in Figure 1. A block diagram of the inspection system is contained in Figure 2; Figure 3 is a bird's eye view of the system being used with the laboratory test billet container.

The inspection system comprises an ultrasonic search unit assembly for transmission and coupling of ultrasound to and from the container, a manually operated scanning system for moving the search unit over the entire bore surface, a facsimile recorder which provides a graphic display of the integrity of the liner, and supporting electronics for signal generation, processing, and recording.

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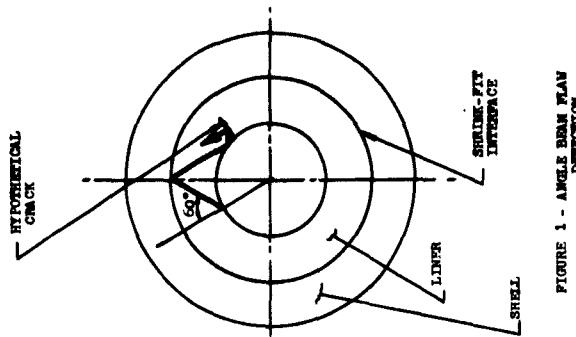


FIGURE 1 - ANGLE BEAM PLAN DEFLECTION

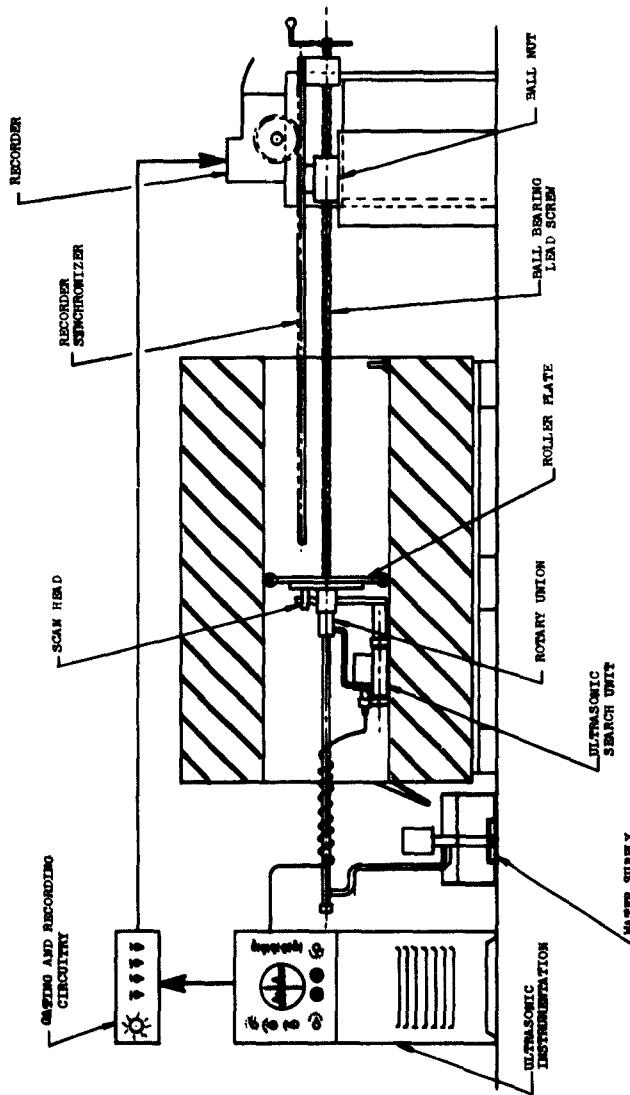


FIGURE 2 - INSPECTION SYSTEM DIAGRAM

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Figure 3 SYSTEM AS USED WITH MODEL BILLET CONTAINER

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The ultrasonic search unit consists of a transducer mounted on a plastic block, one side of which is contoured to the bore surface. Wheels are mounted on the block giving the search unit the appearance of a roller skate, and during scanning, the search unit circumferentially "skates" along the bore surface. Intimate ultrasonic coupling is accomplished through a thin layer of water between the block and the bore surface. This water is supplied through jets in the block coupled to a rotary union which in turn is coupled to a pump situated in a pan located partially under the skid mounted billet container. This pan collects leakage couplant which overflows at this end, the other being dammed, and forms a closed water system requiring about five gallons capacity at a flow rate of 1 gpm.

The search unit is moved spirally over the surface of the bore by a manually operated scanning system. Scanning is accomplished by turning the supported ball bearing lead screw resulting in a helical scan. Rotational speed is not critical and typical rates are in the order of 30 rpm. The lead screw is fitted into the hub of a bearing in a plate with wheels, and the wheel supports are extended to the bore diameter. Since it cannot rotate, the plate simply traverses the bore during scanning and serves to provide support and centering for the scan head attached to the end of the lead screw.

Also fastened to the lead screw through a bearing is a rack. A sprocket driven by the rack converts the lead screw translation into rotational motion which is used to drive the facsimile recorder. By this mechanization, the recorder is synchronized to the search unit position within the billet container.

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The transducer and the recorder are electrically coupled to the ultrasonic test console, consisting of a Sperry UW Reflectoscope and MRD Varigate. The Reflectoscope periodically pulses the transducer and displays returned pulses on the cathode ray tube, forming an A scan. The Varigate was designed to discriminate the return pulses and provides signal impulses to energize the readout of the facsimile recorder. Since the recorder is mechanically synchronized to the scanning system, the recording produced graphically depicts the transducer positions at which crack signals are obtained. Interpretation of the recording then permits defect identification and location.

This interpretation is readily accomplished by placing a specially prepared clear plastic sheet over an inspection record. On this sheet is ruled a grid and when positioned properly, readily gives the longitudinal and circumferential location of radial cracks. An overlay superimposed over a typical record resembles the drawing of Figure 4. The overlay relates the two dimensional record to the specific geometry of the container being inspected thus accounting for tapers and integral discontinuities such as key ways or thermocouple holes.

Referring to Figure 4, the dotted line drawn through the center of the A region represents the crack location on the bore surface, and its position can be readily measured on the overlay in degrees from the 12 o'clock or "vertical" position of the billet container. The width of the region is dependent upon crack depth, and its measurement thus gives an indication of crack depth. By tracing the region outline on the overlay and superimposing it on

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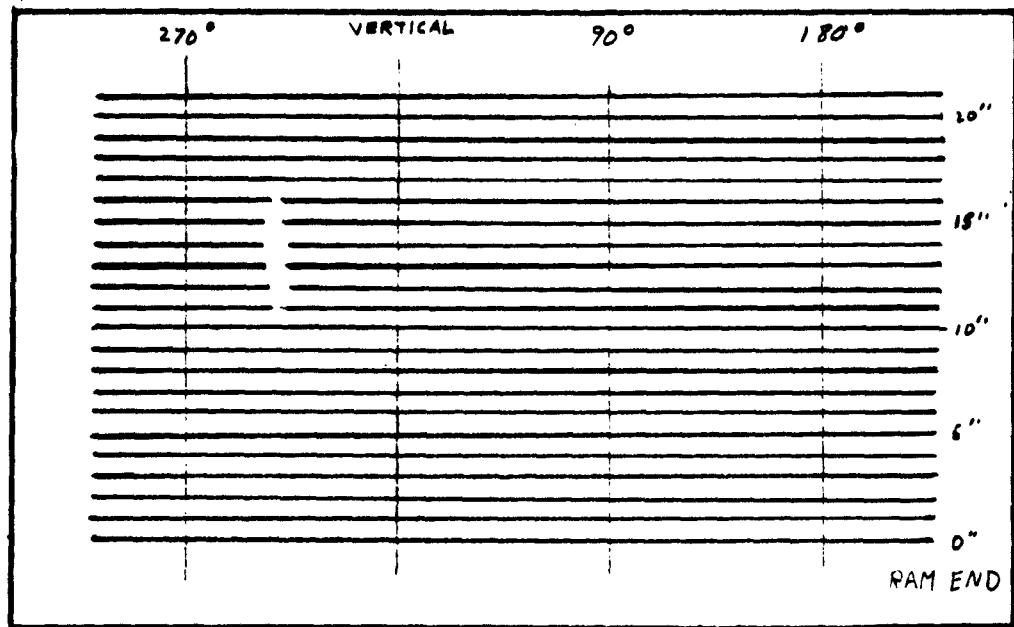


Figure 4 - INSPECTION RECORD FORMAT

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subsequent records, the resulting comparison allows direct determination of changes in crack dimensions due to continued press operation or time.

Accurate determination of crack depth and crack propagation requires that the system possess a high degree of repeatability between successive scans, thus enabling a single scan to be described as a representative inspection record. To test and establish repeatability a large number of runs were made with the model billet container. Some typical recordings are shown in Figure 5. On the recordings, each line represents a displacement of 1 inch along the bore surface and hence, crack indications on successive lines display the origin and extent of cracks within the model billet container. The regions formed by the crack indications have been outlined on the records to increase contrast, and their shape can be observed to be irregular and varied between different regions.

Four large flaw regions are distinct and the average value of the area designated "A" was measured for each scan, giving rise to an averaged value for the ten scans shown. In nine cases out of ten, the area of the third region was within $\pm 10\%$ of the averaged value and in seven cases of the ten, the similarity was $\pm 5\%$.

The depth measuring accuracy of the system has not been experimentally confirmed with the model billet container because the crack depths are not accurately known. This will be determined during the next phase of work. Experiments conducted with test blocks indicate that the accuracy and sensitivity may be of the order of a 1/2 inch within the depth range of the system.

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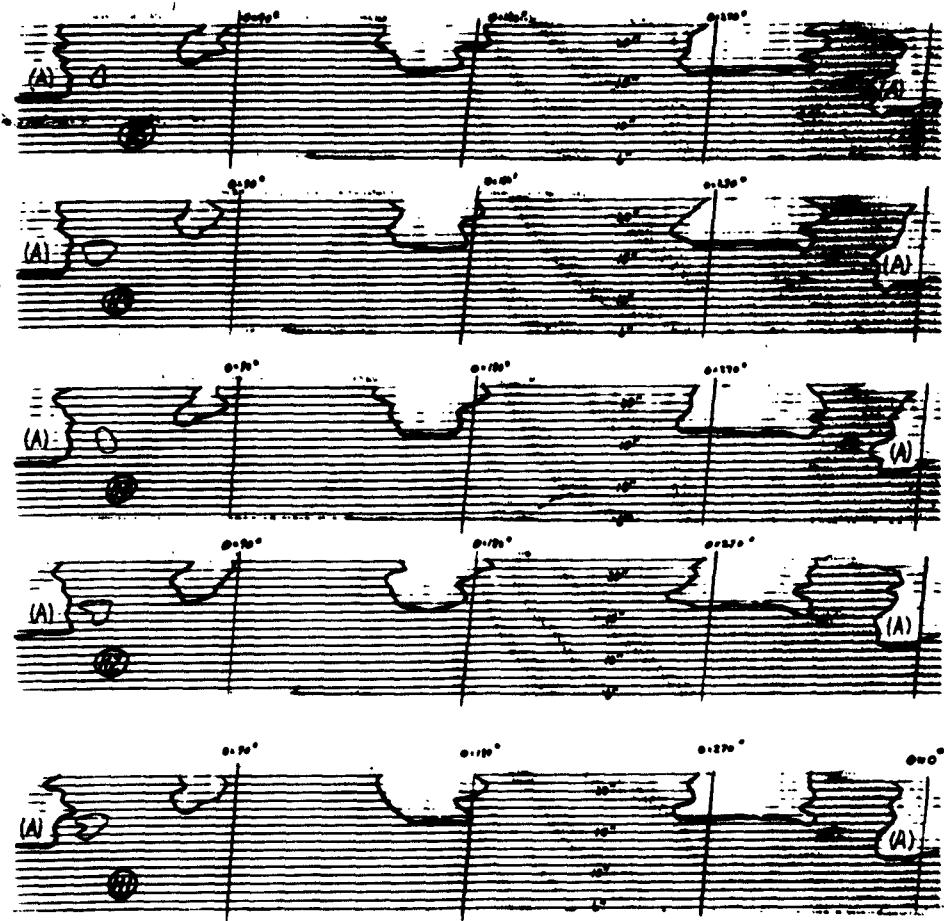
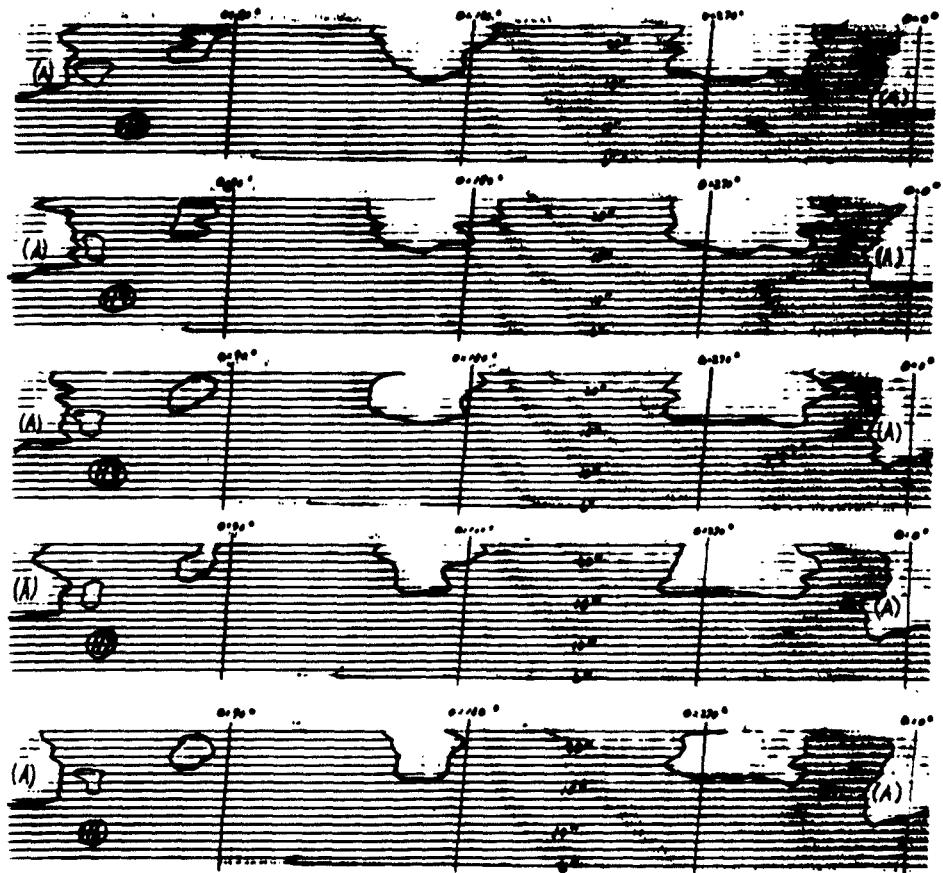


Figure 5 INSPECTION RECORDS OF MODEL BILLET CONTAINER

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Though problem areas yet remain in the development of a universal system, the present system has been performing capably under room temperature conditions with bore surfaces that appear more severe than those anticipated in normal usage.

To date the system has been used only with the model billet container and though capable of being used on operational billet containers, additional refinements in the mechanical design are required to improve its use as a routine maintenance tool. When optimally designed for this purpose, it is estimated that setup time for a particular billet container would be approximately fifteen minutes and can be accomplished by one man. To change from one bore size to another would require on the order of another fifteen minutes and would involve simple changes in the search unit, instrument settings, and adjustment of the roller plate.

2.2 System Development

Present system capabilities resulted through successful integration of the scanning mechanism, search unit, coupling and requisite electronic circuitry. The development of these components and associated tests are described in detail in the section.

2.2.1 Recording and Electronics

The facsimile recorder consists of a rotating spindle upon which is mounted a helically wound, spring loaded, stainless steel wire; the spindle being rotated one revolution for each lead screw revolution. The recording paper is 11 inches wide, passes between the helix wire and a second fixed

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filament, and is advanced at a rate equal to one tenth the lead screw translation. The lead screw pitch is one inch; thus for each revolution, the longitudinal displacement of the search unit is one inch, but the paper advances only 0.1 inch. Since the nominal length of heavy press billet containers is eighty inches, the corresponding inspection record is eight inches long.

The recording is produced by electro-deposition of the filament upon the moist paper. The helically wound electrode is in point contact with the fixed electrode through the paper, and if the fixed electrode is at a negative potential, metal is deposited and a paper discoloration occurs. The "no flaw" indication is the dark line, thus a loss in recording signal appears as a flaw also. Since the helix spindle rotates in synchronism with the scanner, the point contact traverses the paper, thus producing a line of discoloration across the paper width and effectively reproduces the search unit's path along the bore surface identical but reduced in scale to that observed if the bore surface were longitudinally cut and unrolled.

To produce the recording signal, a transistorized gating system termed the MRD Varigate was built. The system's block diagram along with corresponding circuit diagram are shown in Figures 6 and 7. Its operation will be explained through use of the waveforms shown in Figure 8.

The first waveform shows the differentiated pulses produced by the pulse rate generator in the ultrasonic instrument. T_p is the time between pulses and its reciprocal is the pulse repetition rate in pulses per second. This signal is entered into the system as the synchronizing signal and triggers

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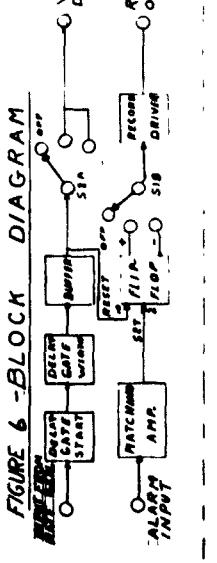


FIGURE 6 -BLOCK DIAGRAM

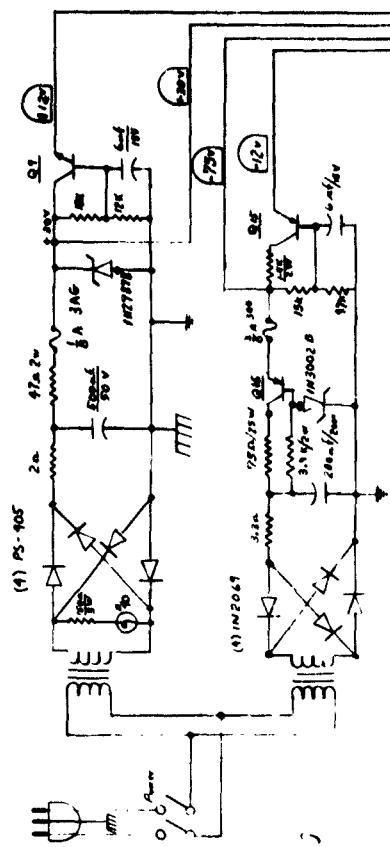
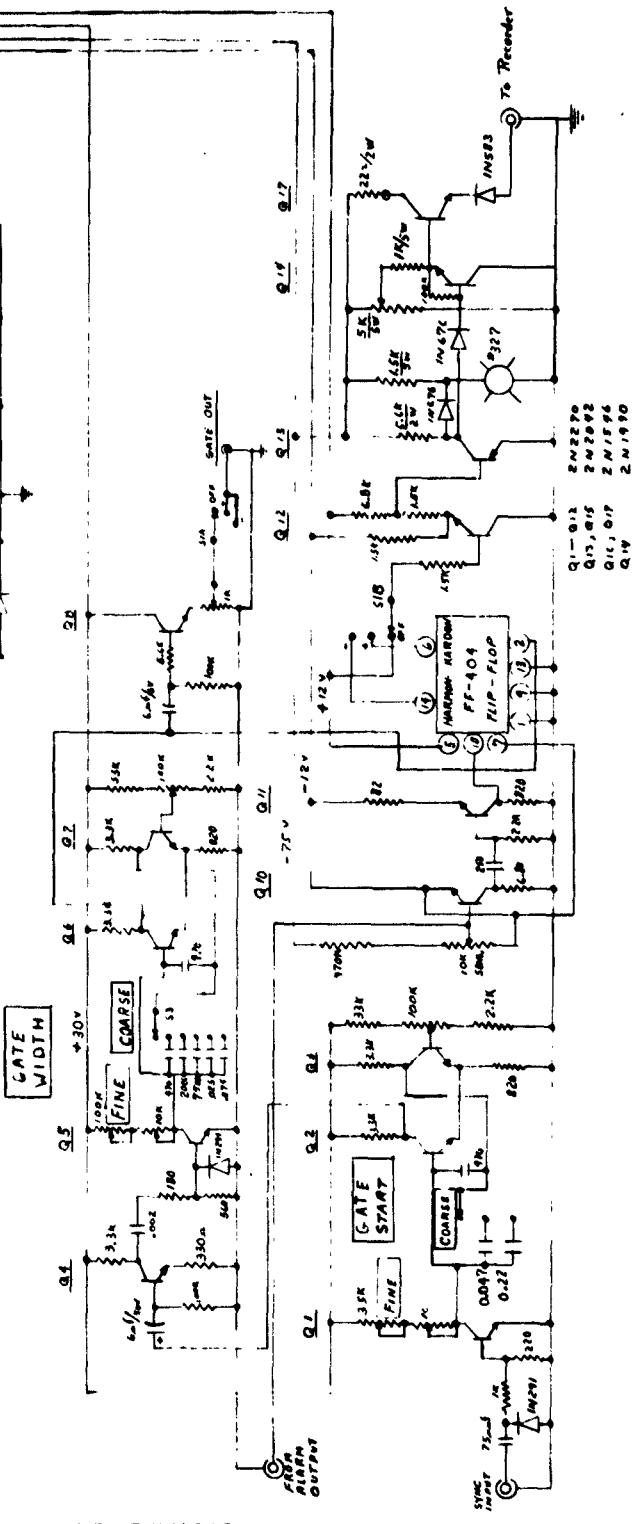


FIGURE 7 - GATE & RECORDER DRIVER SCHEMATIC



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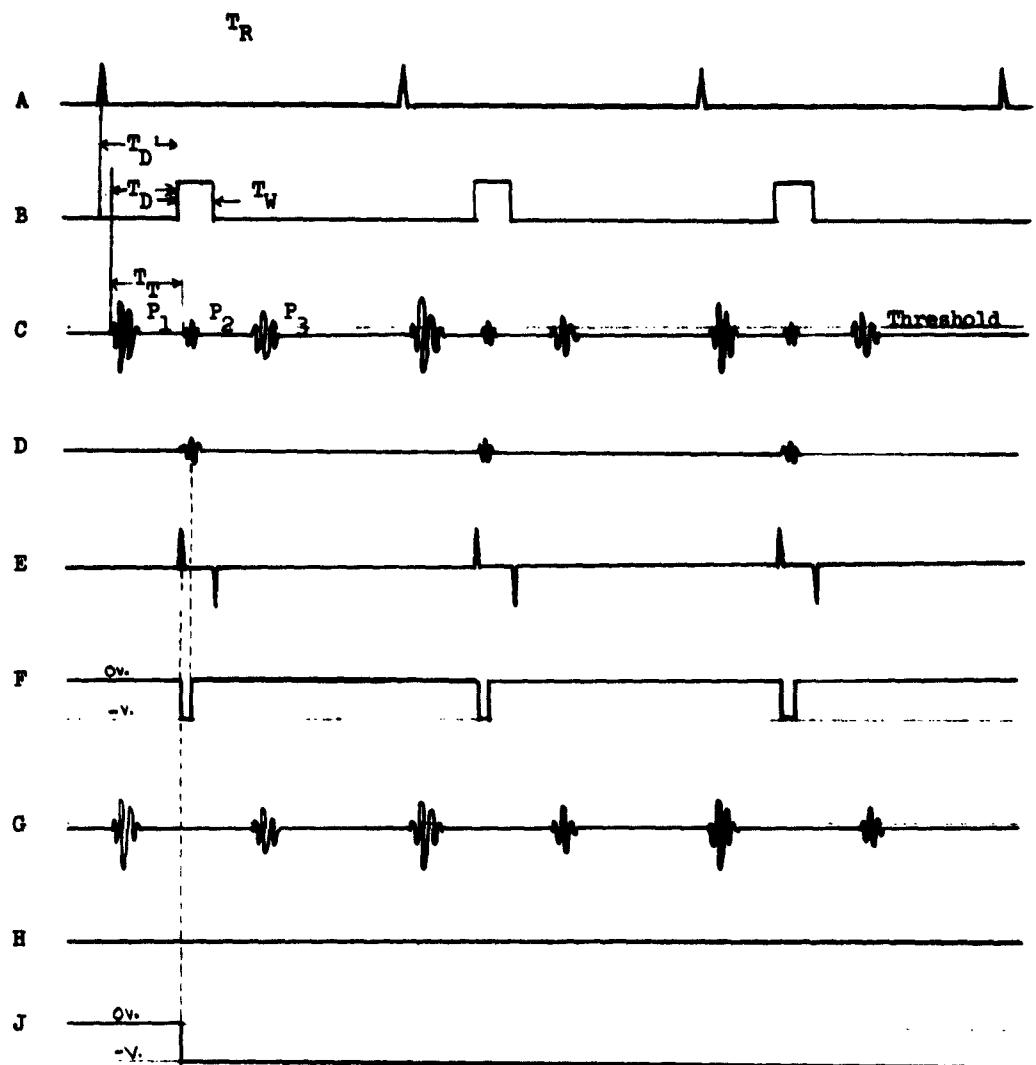


Figure 8 - GATING WAVEFORMS

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a delay circuit. At the completion of the delay, a differentiated pulse is produced which triggers a second delay circuit producing the second waveform termed the gate pulse. T_W is the duration of the gate pulse and in operation this is calibrated in inches of steel knowing the velocity of sound in steel. T_D is the delay time of the first delay stage and is similarly calibrated. Both of these are variable with coarse and fine controls to permit accurate settings.

Waveform C shows the ultrasonic pulse as generated and received by the ultrasonic instrument. Slightly delayed from the synchronizing signal, P1 is the pulse produced by the transducer upon application of a D.C. pulse. The transducer mechanically vibrates sinusoidally at its resonant frequency transmitting a "tone burst" into the inspected part. If a flaw is present, pulse P2 is reflected back to the instrument and is received a time T_T later, this being the time required for it to travel to the flaw and back. For each container to be inspected, this distance can be calculated and T_D and T_W adjusted so that P2 is included within the gate period. Note that P3 which occurs due to the ultrasonic pulse reflecting from some other "flaw", located further within the billet container (e.g., a heater hole) is not coincident with the gate pulse and is thus discriminated against.

This waveform is then passed to an alarm circuit (not included in this design since the instrument possessed one) which produces an output only if a pulse is coincident with the gate pulse and is above a minimum amplitude or threshold. Assuming that P2 is greater in amplitude than the threshold, the output appears as in D.

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E is the differentiated gate signal and together with the signal shown in D, are passed to a flip-flop which is sensitive only to positive impulses. E is used to reset the flip-flop and D is passed to the set input. The flip-flop output is amplified to drive the recorder and the output takes the form shown in F. The periodic resetting of the flip-flop produces a negative voltage at the recorder output which discolors the paper until the presence of a pulse from the gated alarm. When this occurs, indicating the presence of a crack, the output switches to zero volts and the paper appears white. As shown, the white flaw signal is interspersed with dark spots but in normal operation with a steady flaw signal, no dark spots occur since the duration between reset and set is sufficiently short that the recorder integrates this effect.

If no crack were present, the waveform C would appear as G, the gated alarm output as H and the resulting signal as J. Under this condition, it can be seen that the recorder produces only a dark line.

Functioning in this manner, the highest degree of flaw resolution is obtained at any pulse repetition rate, thus enabling simplified data interpretation. The gate is capable of isolating flaws to within a quarter of an inch over a range from 1/4" to 20 feet of steel.

2.2.2 Coupling

Much effort has been expended in the investigation of coupling techniques amenable to in-press inspection. This effort has in general been limited by available materials and until recently, elevated temperature coupling was

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achieved only by using water in direct contact with the test surface. Experiments with water coupling led to the design of the "roller skate" coupler which is effectively a mobile gap coupler. Though previous reports discussed success with gap coupling at elevated temperatures, the "roller skate" search unit has been used only at room temperatures. It now appears that a tire fabricated of high temperature silicone rubber offers a more practical approach to the coupling problem. The following subsection discusses the various coupling methods investigated during the report period.

2.2.2.1 Liquid Coupling

Two types of liquid couplers were investigated during the report period. One is shown in Figure 9 and consists of a cylindrical teflon jacket contoured at one end to conform to the container bore surface, and holding an ultrasonic transducer by press fit. The unit is inclined at an angle of 23 degrees with respect to the surface normal, thus permitting a shear wave to enter the container at approximately 60 degrees. Teflon was used with eventual high temperature application in mind and to minimize sliding friction between the coupler and bore surface.

Tube fittings were inserted into the sides of the jacket and water was passed between the transducer and the bore transverse to the transducer face. Water leakage between the jacket and the bore collected in the bottom of the bore and one end of the model billet container was dammed to a height of an inch. A pan was placed beneath the billet container at the other end to collect the leakage. A recirculating pump in the pan supplies the coupler through tubing, thus forming a closed water system.

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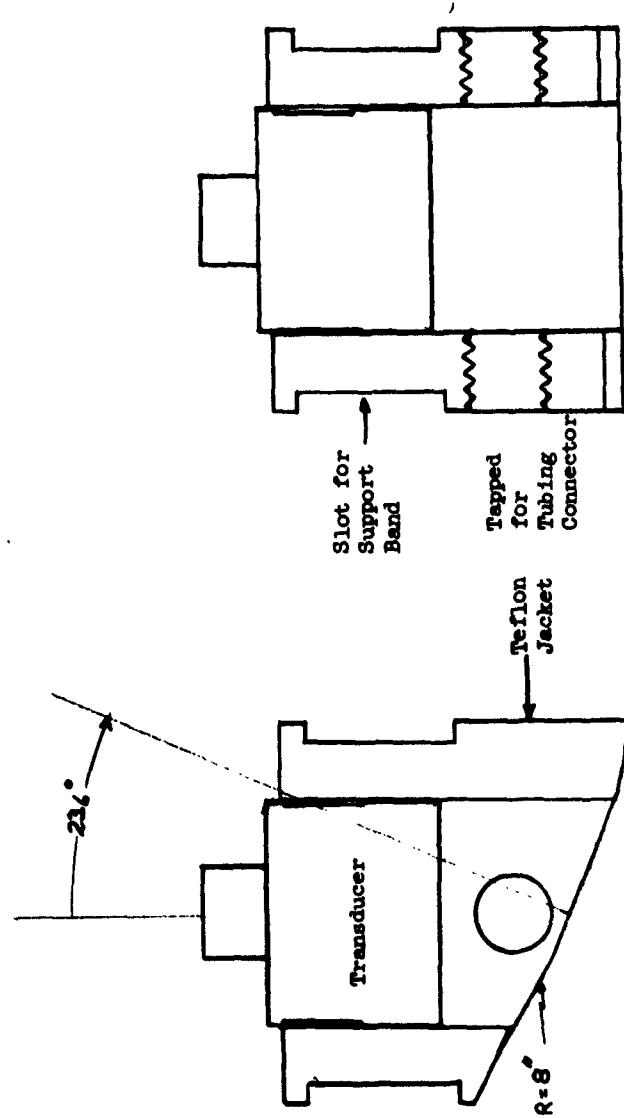


Figure 9 - GAP COUPLER

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One difficulty encountered with the teflon coupler was the problem of maintaining coupling while scanning the failed billet container. Due to the large liner crack present at the die end, the bore shape progressed from circular at the ram end to elliptical near the die end, giving rise to an asymmetrical bore. As the scan head progressed within the bore, lead screw concentricity within the bore could not be maintained since gravity forced the roller plate to rest on the bottom of the bore and the coupler would lift off of the bore surface when rotated past the top. This lift off became sufficiently large that water contact with the bore surface could not be maintained. This was dependent upon flow rate and adjustment of the roller plate.

Another difficulty observed was the entrapment of air within the gap and was attributed to the loss of bore to jacket seal and tangential forces produced by the coupler rotation. This force tends to make the water accumulate within the gap at the trailing side of the jacket and create a void at the other. Due to the imperfect seal, air would rise to the pocket and become entrapped at the transducer face when the coupler passed the bottom. Water flow rate and scanning speed both affected this condition, as did the deviation of the bore radius from the radius of the end of the coupler. In addition, the irregularity of the skin layer affected the jacket to base seal.

When pulse echo testing with this coupler, spurious surface wave reflections were observed. These were generated due to beam spread and bore curvature and often were confused with crack indications. These indications could be readily separated when manually inspecting; however, they would be difficult to discriminate in an automated inspection system.

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These observations led to the design of the second coupler, a "roller skate" search unit shown in the bore of the model billet container in Figure 10. To minimize the influence of the gap spacing variation on coupling, a 150 lb. horseshoe magnet is used to maintain constant adherence of the coupler to the bore surface. In this manner, the bore supports the search unit and the scanning mechanism now serves only to guide the path of the unit.

The photograph of Figure 11 depicts the search unit with the magnet removed. Steel pole pieces for the magnet were turned to the bore radius and pressed into a plastic block similarly turned. The magnet is placed on the pole pieces and straddles the transducer fastened to the block. The transducer is angled relative to the bore surface and the plexiglas acts as a refractive material in generating a 60° shear wave for inspection.

The slots visible within the block reveal the manner in which water is diverted over the area the ultrasonic pulse must pass through in coupling. By placing jets on both sides, water freely covers the area independent of coupler position on the bore surface. The gap between the base and the block is adjustable, typical spacings being 0.020" to 0.050". The larger gap, though requiring a larger flow rate, was employed to facilitate scanning over depressions or projections on the model billet container bore surface without causing lift off of the block.

No difficulties have been observed to date with spurious surface wave reflections, the presence of water in the large gap area serving to damp them. Reflections within the block and in the gap limit the minimum liner

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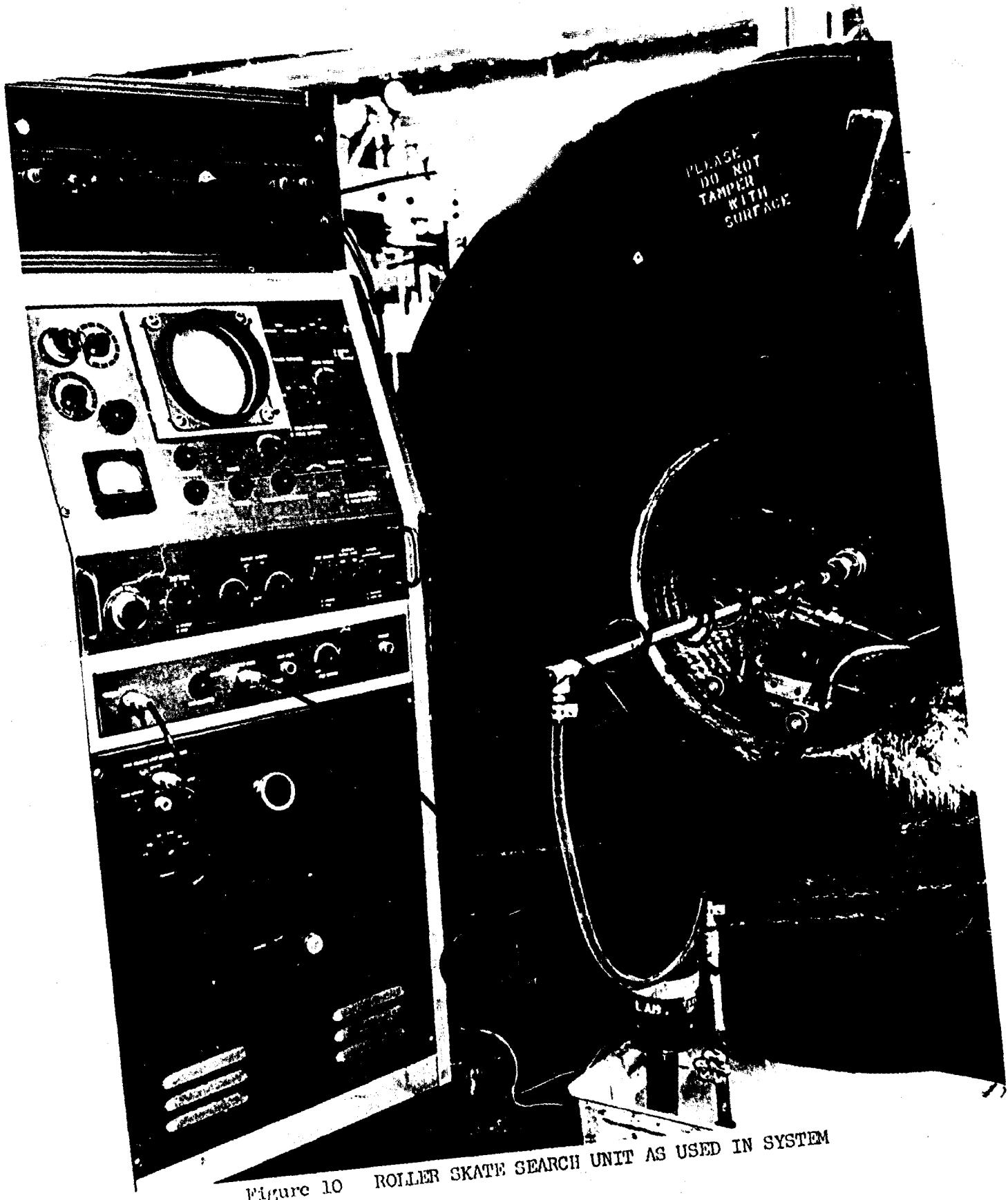


Figure 10 ROLLER SKATE SEARCH UNIT AS USED IN SYSTEM

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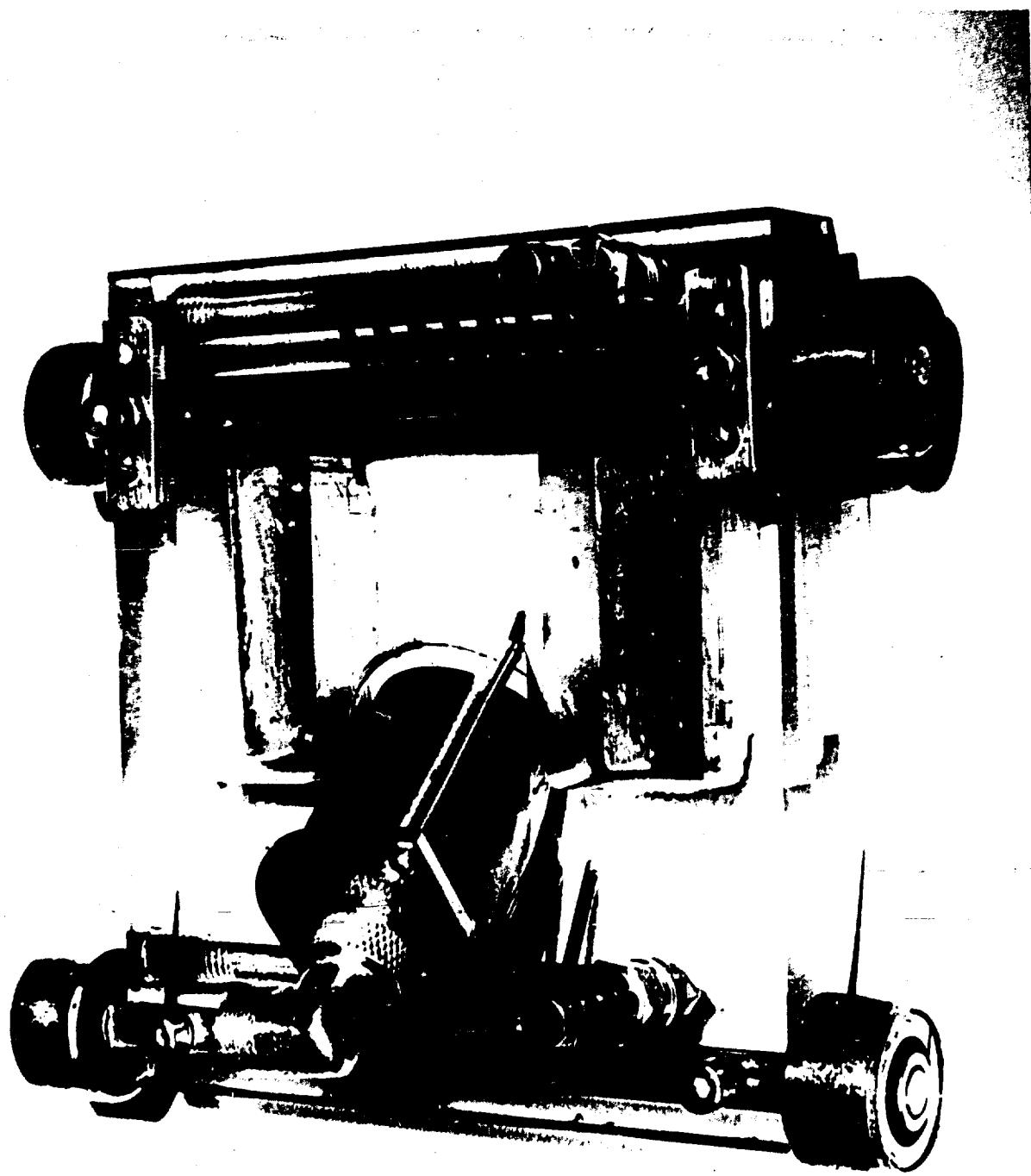


Figure 11 ROLLER SKATE SEARCH UNIT

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thickness that can be inspected but have not limited inspection of the model billet container. These can be eliminated with coupler refinement, however, the prototype coupler design was a compromise between ultrasonic performance and both coupling and mechanical considerations. Another design has been made for a smaller unit to permit inspection closer to the ends; however, fabrication was delayed to include refinements found beneficial through continued use of the prototype unit.

2.2.2.2 Wheel Search Units With Grease Couplant

The use of a wheel search unit with grease couplant was considered as an alternate solution to in-press inspection. Units employing adiprene rubber tires are commercially available but unsuitable for elevated temperatures. In the previous quarterly report, the use of a metal tire was suggested for high temperature use. To test the concept, a design was made and a mold fabricated for forming a metallic tire by the electrodeposition process. Figure 12 shows the split core mold and one of the two tires formed on this mold.

Readily visible in the tire photograph is the presence of thin seams resulting from imperfect alignment of the mold sections. However, the main factor limiting their use was their lack of compliancy, even though the thickness was only 0.005". In addition, localized hard and soft spots were observed when rolling the tire over a flat surface. Upon the fabricators recommendation, one unit was annealed at a temperature of 700°F for 24 hours and though the anneal enhanced compliancy, the improvement was insufficient to provide suitable coupling. It does not appear that the compliancy problem with metal tires can be solved for some time. The investigation was therefore directed toward the

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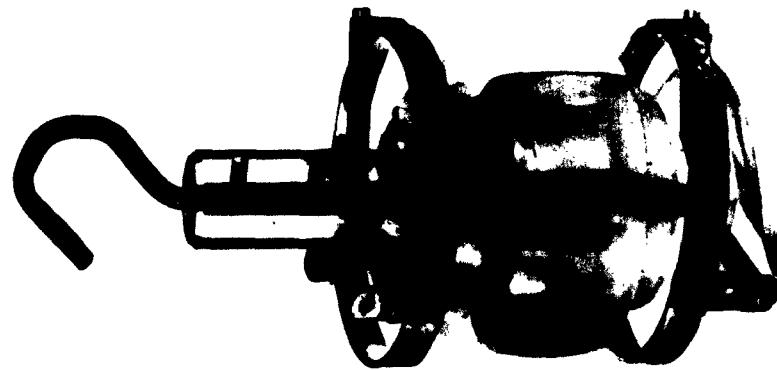


Figure 12 METAL TIRE AND MOLD

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use of a silicone rubber tire to withstand the thermal requirements. Silicone rubber is compliant at elevated temperatures, and in addition, its low thermal conductivity provides thermal isolation between the transducer and bore surface. Assuming a wheel search unit with a tire diameter of six inches and the interior filled with water, calculation has shown that the water temperature would rise about 110°F in scanning over a 1000°F surface for a five minute period.

With this consideration, no difficulties are foreseen in containing within the tire casing a transducer capable of operating to 400°F. And due to the scanning time required, it is anticipated that no additional cooling would be required to maintain the transducer temperature to a safe operating temperature, thus simplifying the requirements of the scanning mechanism.

Additional impetus towards the development of such a unit for high temperature inspection was gained at the recent World's Metal Show when the successful use of a water column coupler sealed at the working end with a silicone rubber pad was described for "on stream" inspection in chemical plants at temperatures to 900°F.

Several silicone rubber fabricators were consulted, and rubber samples tested to determine their coupling capability at elevated temperatures. A 2.25 Megacycle transducer was press fit into a tube which was subsequently filled with water. The samples were held to the tube end by evacuating grooves milled in the wall at the sample end. The first trace in the oscillograms of Figure 13 shows the signal pattern received before the assembly was coupled to a one inch test block. The first echo is that from the water-rubber

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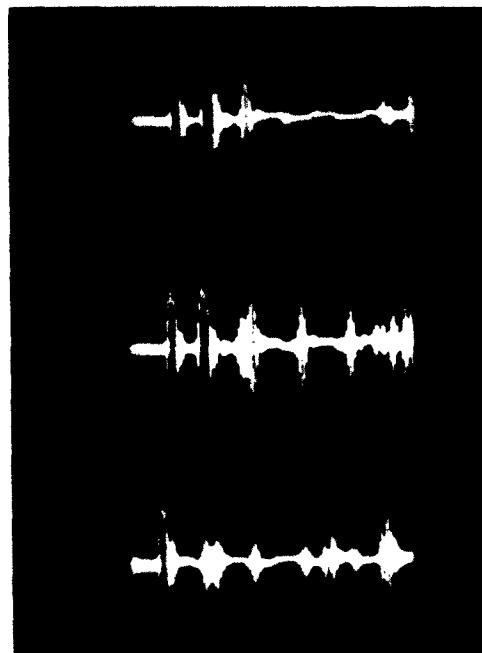
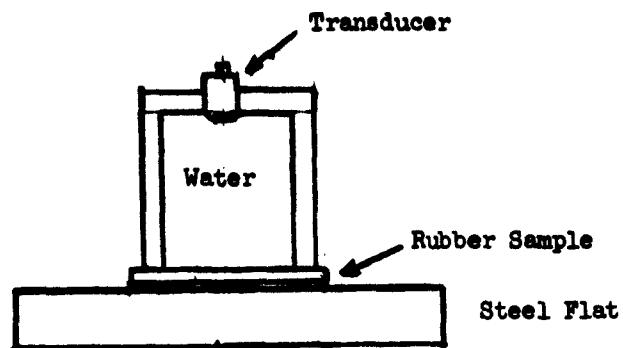


Figure 13 - INDICATION RECEIVED IN SILICONE RUBBER TEST

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interface while the second is the echo from the working side of the rubber, the third echo simply being a multiple of the second. When the unit was pressed onto a 1" steel plate coated with Dow #41 silicone grease, the multiple echo pattern in the steel was observed as in the second trace. The echo pattern in the third trace shows that coupling could be achieved in the same manner when the flat temperature was 600°F though it degenerated in comparison to room temperature coupling.

These observations suggest the ability of silicone rubber to couple ultrasound and simultaneously provide scanning mobility and thermal isolation for high speed elevated temperature inspection. A wheel search unit of the design considered would thus be capable of functioning under any billet container inspection requirements. However, at high temperature the tire lifetime may be limited to only a few scans and thus be an expendable item. It is anticipated that replacement costs of the expendable tire surface will be sufficiently low so as not to militate its use.

2.2.3 Crack Depth Measurements and Beam Transmission

Described in the previous report was the use of angle beam reflected through transmission for determining crack depth. The results of the initial tests performed on a 5" steel test block indicated that the depth of cracks equal to or in excess of 3/8" could readily be determined within $\pm 1/16"$. Further improvements were made in the setup to increase sensitivity and determine the lower limit of inspection. The apparatus used is shown in the photograph contained in Figure 14.

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Figure 14 TEST SETUP FOR MEASURING CRACK DEPTH

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Two linked plastic wedges were used to transmit and receive the angle beam. A masking strip was placed between the wedge and the transducer to improve sensitivity to small flaws. The surface of the test block was coated with oil and the amplitude of the signal observed as the holder scanned over the flaw. The response for several different test conditions is shown in the plots of Figure 15. The amplitude of the signal when not in the vicinity of a crack was taken as 30 units.

Figure 15a, obtained during this initial test, is the response to a 3/8" deep crack at a frequency of 2.25 Megacycles, an inspection angle of 45 degrees shear, and the masking strip being 1/4" wide. Subsequent responses were all performed at an inspection angle of 60°. In the next figure, the response to a 5/16" crack shows a greater amount of signal change even though the crack size was less and can be attributed to the increase in inspection angle. At the same crack depth, the masking strip width was reduced to 1/8" and showed no increase in sensitivity as indicated by the similarity of Figures 15b and 15c. Comparison of Figures 15b and 15d show the effect of changing the inspection frequency to 5 Megacycles.

At a crack depth of 3/16", the response shown in Figure 15e was obtained with a test frequency of 5 Megacycles and using a 1/4" masking strip. Note that this response shows considerable improvement over the first case considered for one half the crack depth.

The availability of the scanning system permitted extension of the flat block tests to the model billet container. The teflon couplers were used with transducers operating at 2.25 Megacycles masked with 1/4" strips.

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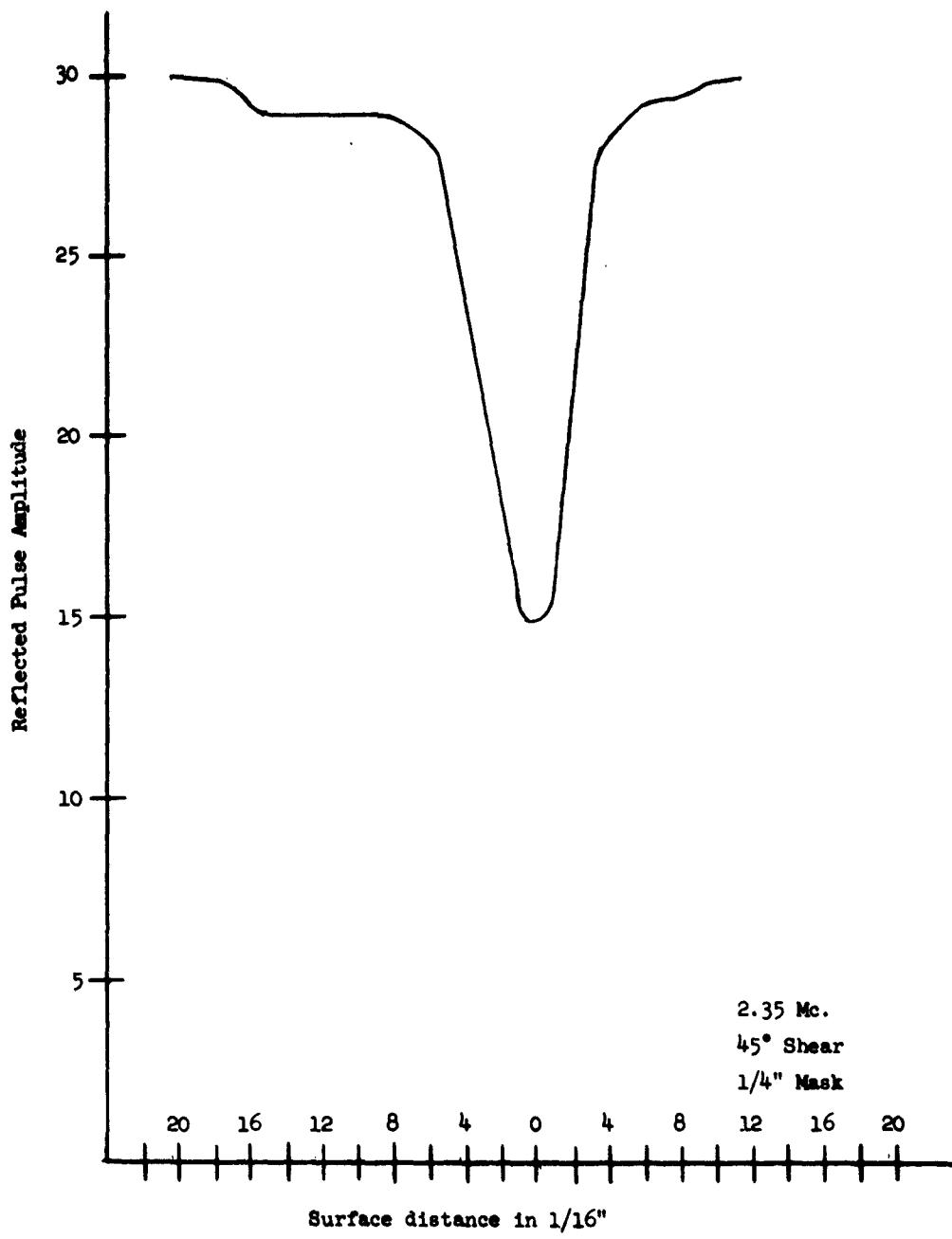


Figure 15a - RESPONSE FOR SLOT DEPTH OF 3/8"

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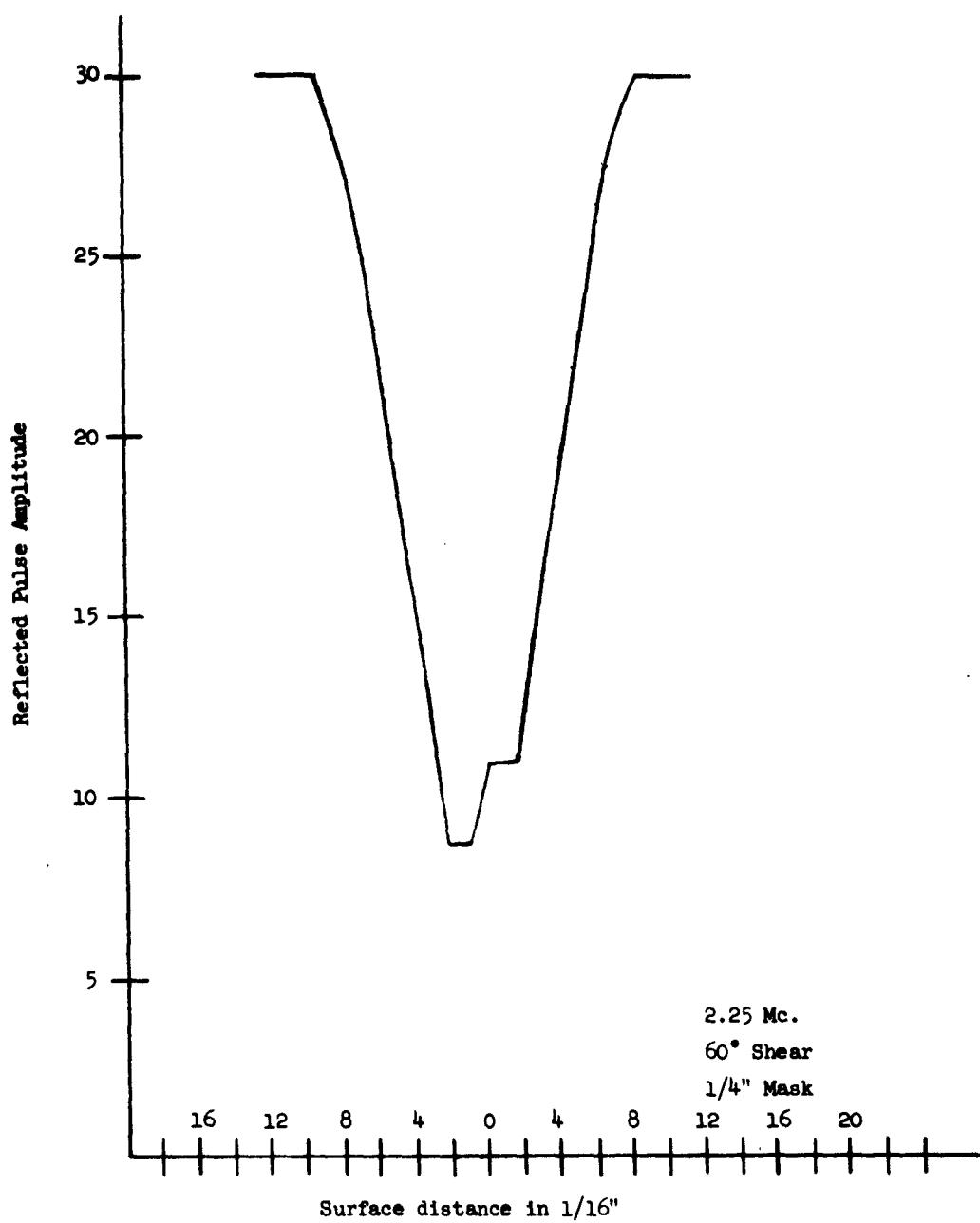


Figure 15b - RESPONSE FOR SLOT DEPTH OF $5/16$ "

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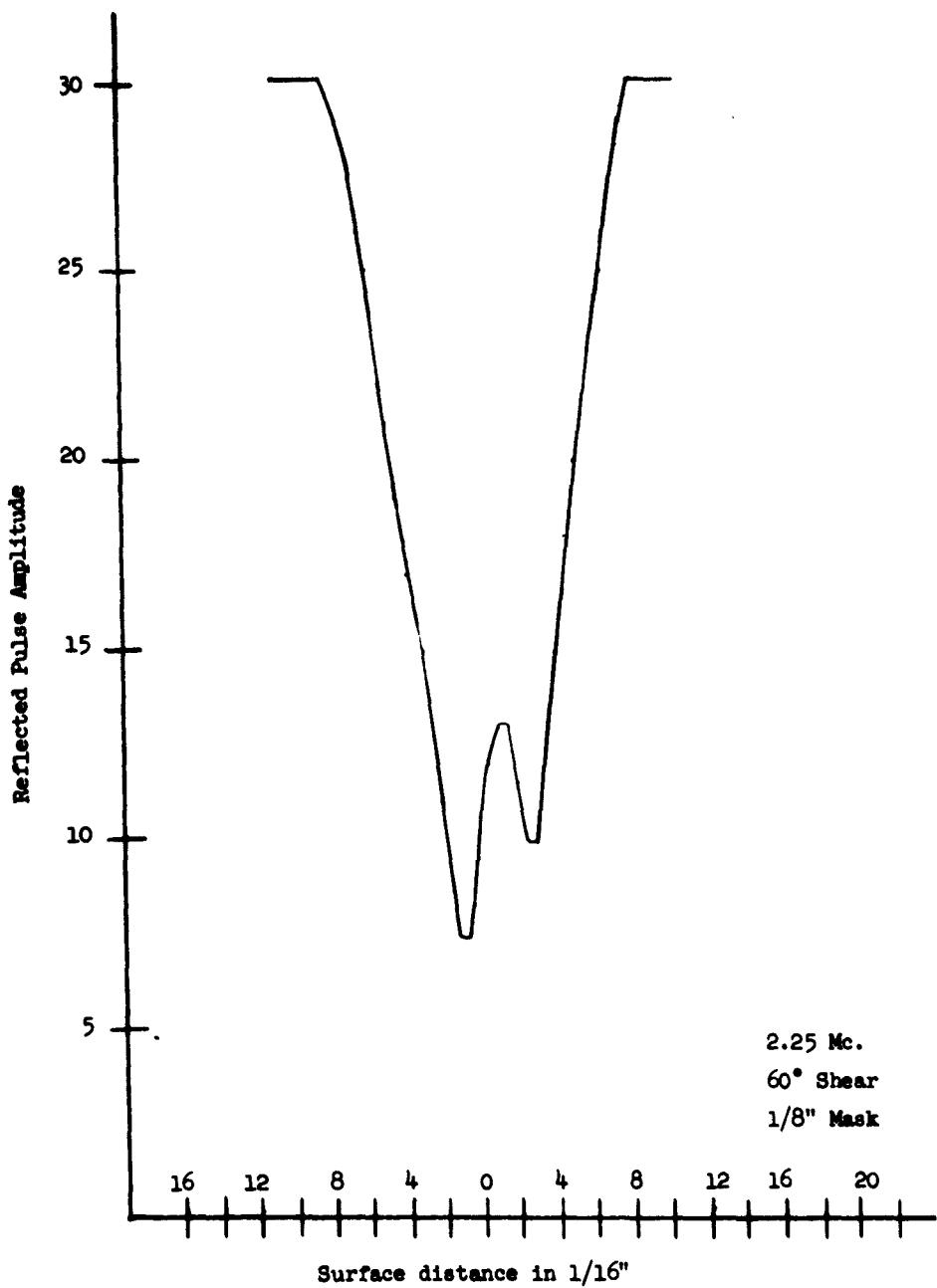


Figure 15c - RESPONSE FOR SLOT DEPTH OF 5/16"

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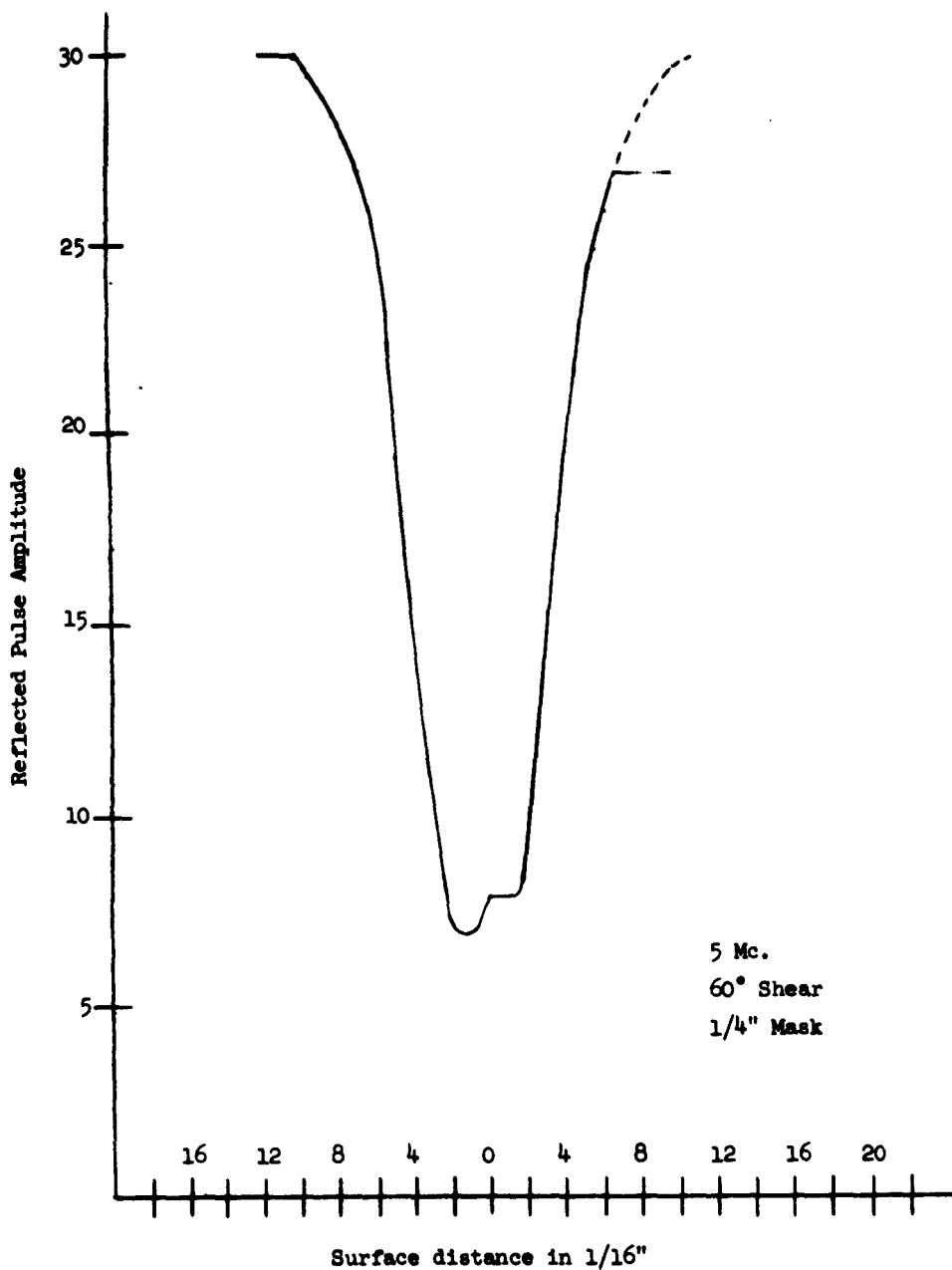


Figure 15d - RESPONSE FOR SLOT DEPTH OF 5/16"

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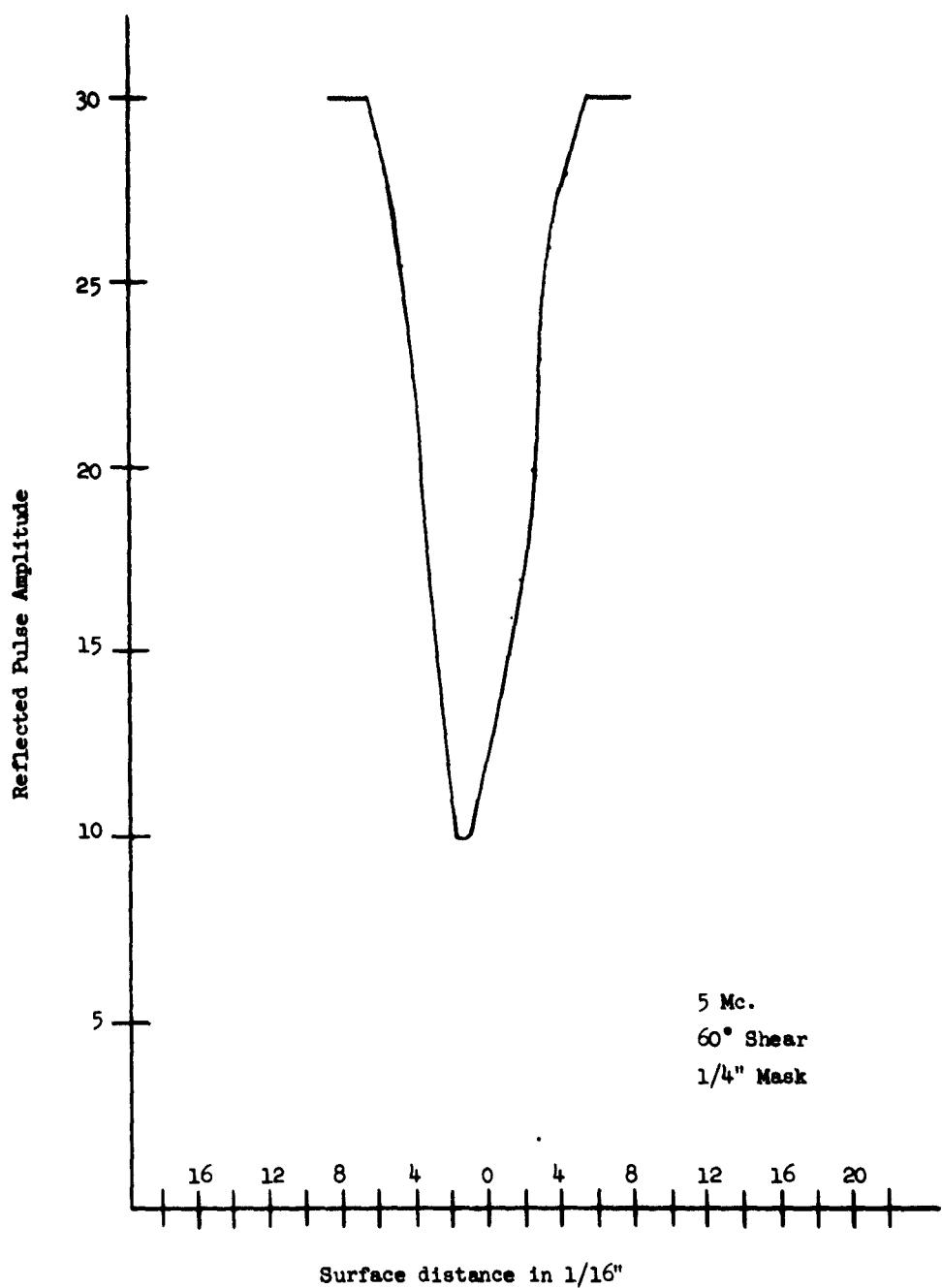


Figure 15e - RESPONSE FOR DEPTH OF 3/16"

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A serious problem presented itself immediately upon the initiation of container tests. The steady no flaw signal, necessary for through transmission inspection and obtained in testing the flat block, was not obtainable with the model billet container. To determine if coupling variations were the source of trouble, the bore was half submerged and testing continued. It was found that small irregular patches of skin layer affected the signal amplitude. To relieve this problem most of the patches were ground off and the transducer masking strips were removed to reduce the sensitivity to surface effects. However, even then, a variation in signal amplitude occurred as the transducer was moved over the surface that could be attributed only to changes in the reflective properties of the shrink interface. During the course of correspondence with a billet container fabricator, a similar inconsistency in shrink fit reflective properties were expressed even with newly fabricated assemblies. This renders through transmission testing of questionable value unless the normal variations can be mapped and separated from crack responses.

Subsequently, pulse echo testing with only one coupler was tried and with marked success. Crack indications could be obtained and "tracked" as the coupler was moved about. However, spurious reflections were obtained and determined to be due to surface waves. Interesting to note was the fact that these surface waves could be readily damped out with the finger on sections both with and without a skin layer suggesting that the wave propagated in the layer as well. This raises some questions as to the cause of the reflections for they seemed also to propagate under spotty layers.

As a result of these observations, it was concluded that the pulse echo method offered the most promise for reliable automated inspection. The

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consistency in return signal amplitude required for through transmission inspection was determined to be unobtainable due to billet container anomalies. This method may still be used for localized determination of liner crack depth. In such a case, the pulse echo technique would be used to locate cracks with subsequent re-examination by through transmission to critically determine crack depth. This effort however, will not be pursued until sufficient background can be obtained through use of pulse echo method to merit its consideration.

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2.3 Evaluation with Model Billet Container

It is in the area of data analysis that much effort has been concentrated, since the inspection record serves to form the basis upon which liner integrity may be determined. The manner in which a record can be interpreted has already been detailed, and system usage with the model billet container in the study of detecting cracks has revealed indications which prove the validity of the technique in detecting cracks. Simultaneously, many unanticipated indications have appeared which may cause discrepancies during system usage on operational billet containers. An analysis of the data interpretation method is essential for evaluation of test results.

The form of inspection records is readily related to crack position through the use of plastic overlays. Since the grid line locations on these overlays take into consideration the system and the dimensions of the particular billet container, then for each container design a new overlay is required if a meaningful interpretation is to be made. Different overlays can be readily made since a simple mathematical relationship exists between crack location and the transducer positions at which crack signals are obtained. This may best be described in cylindrical coordinates and the "vertical" or 12 o'clock position at the ram end will be used as a reference to permit determination of the "vertical" line location on an overlay.

From Figure 16, it can be seen that an arbitrary crack is located at an angular position θ given by

$$\theta = \alpha + \beta - \gamma \quad 1.)$$

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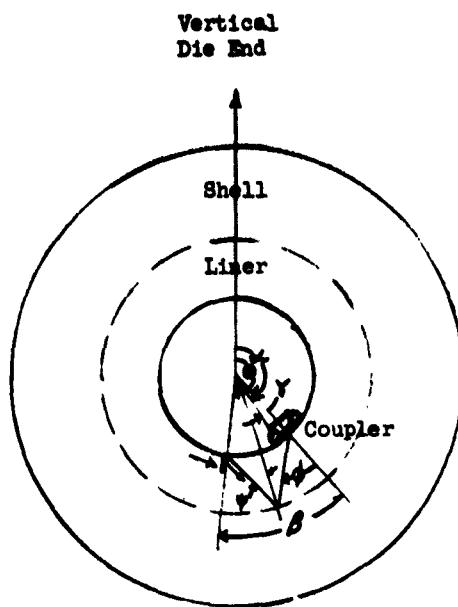


Figure 16a - ANGULAR POSITION SKETCH

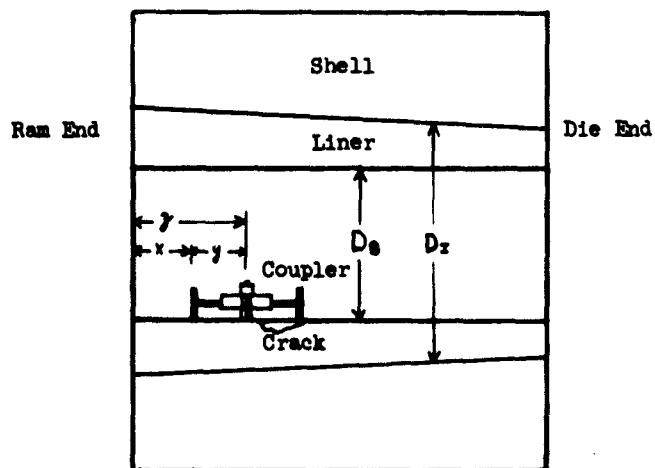


Figure 16b - LONGITUDINAL POSITION SKETCH

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where

θ = Clockwise angle at the ram end made between the vertical and crack position

β = Included clockwise angle between transducer and crack

γ = Included counterclockwise angle between transducer and coupler leading edge

α = Clockwise angle at the ram end made between true vertical and leading edge of coupler.

The leading edge of the coupler is used since this simplifies measurement of α .

In a similar fashion, the longitudinal crack position is given by

$$z = x + y \quad 2.)$$

where

z = longitudinal position of crack

y = displacement between transducer center and wheel edge

x = displacement between wheel edge and ram end.

In terms of these definitions, the recorder describes the locations x and α at which crack signals were obtained which are then related to the actual crack positions z and θ by the stated equations. The terms y and γ are obtained from the coupler design drawing while the term β is dependent upon the dimensions of the billet container under inspection and the inspection angle. This angle is given by

$$|\beta| = 2[\phi - \arcsin \left(\frac{D_B}{D_I} \sin \phi \right)] \quad 3.)$$

where

D_B = Bore diameter

ϕ = Inspection angle

D_I = Diameter of reflecting shrink interface

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The sign of the angle can be either positive or negative respectively dependent upon either clockwise or counterclockwise direction of the ultrasonic pulse, and is a constant for the nontapered designs used in the heavy press program, is plotted as a function of diameter ratio in Figure 17 for the range to be encountered in inspecting the operational containers.

Another factor to be considered is the synchronization between the recorder and the coupler, that is, though the coupler is in position to detect a crack located at $\theta = 0$, the recorder position may be midway across the paper width. However, this is readily compensated for by shifting the plastic overlay over the width of the paper to a position determined by experimentally performing a bore scan. The recording of Figure 18 shows a scan performed to determine this. The starting point of the scan represents the helix position at the time that the leading wheels of the coupler were at the bore vertical. The end point represents the same ($\alpha = 0$) condition after ten revolutions. By connecting these two points with a line, the position of the "vertical" is determined. Note that it is not perpendicular to the scan lines showing a slightly imperfect conversion of lead screw translation.

From a drawing of the coupler, the value of γ was measured to be 26.8 degrees. Since the model billet container shrink interface is tapered, β at $\phi = 60^\circ$ varies approximately linearly from 63.4 degrees at the ram end to 50.6 degrees at the die end. Over the region which was capable of being scanned, a median value of 59.8 degrees was taken. In this manner, it is determined that the actual crack position "lags" the $\alpha = 0^\circ$ line by 86.6° and thus, the $\theta = 0^\circ$ line was drawn on the record and copied onto a plastic overlay for use in interpreting other recordings such as that of Figure 19.

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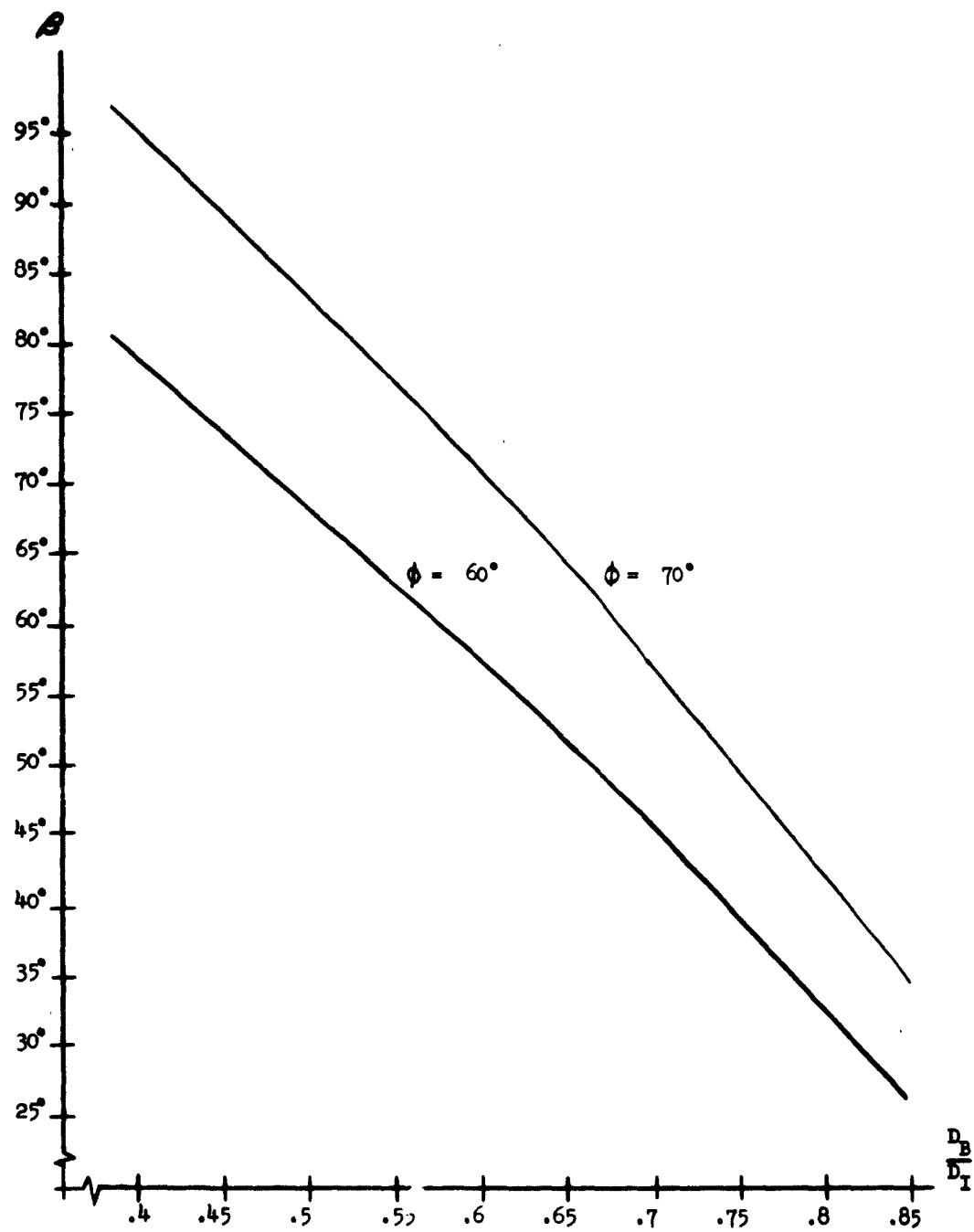
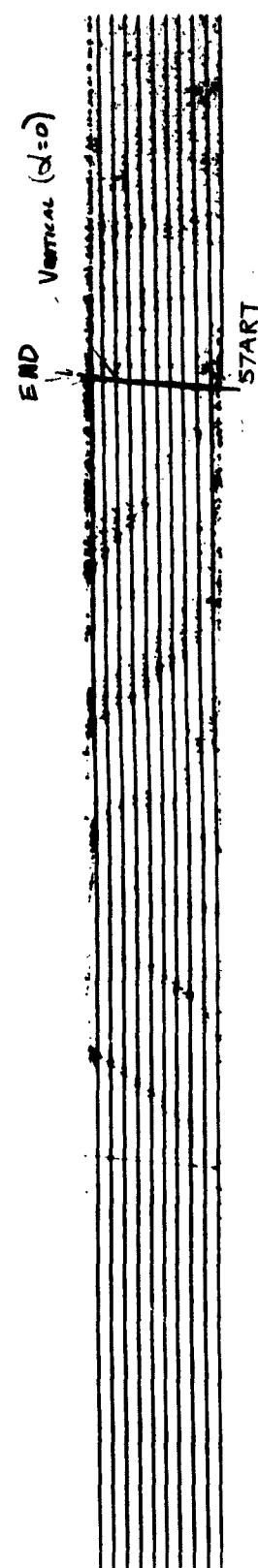


Figure 17 - TRANSDUCER-CRACK ANGULAR SEPARATION

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Figure 19 INSPECTION RECORD DEPICTING CRACK ORIGIN AT
12 INCHES FROM RAM END OF MODEL BILLET CONTAINER



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This record was obtained at a test frequency of 2.25 Megacycles and the θ lines were drawn on after superimposing the overlay. The initial starting position was 2 inches from the beveled ram end and the coupler offset is 4 inches, thus the initial line is the $z = 6"$ line. One flaw region is present on the vicinity of $\theta = 0^\circ$ and is first visible on the sixth revolution or alternately, at $z = 12$ inches.

To confirm the presence of this crack, inspection from the ram end was performed with a $3/4"$, 5 Megacycle transducer. Oscillograms of received signals at different locations are contained in Figure 20. In these oscillograms, each step mark equals a distance of three inches and "r" is the radial distance from the bore surface to the center of the transducer.

Inspection in this manner does not permit the determination of crack longitudinal origin but it does infer that if detectable in this manner, the crack should be detected by the system. Examination of the first trace reveals the presence of a crack at $z = 16$ inches. However, the plan view record indicates that the crack was detected by the system and determined to extend at least within 12 inches of the ram end. Further inspection from the end in the same vicinity reveals the radial extent of the crack, namely, at $z = 16$ inches, the crack already extends nearly through the liner. The third trace shows that reflections are also obtained over a fairly wide angular range suggesting either a band of cracks in the vicinity of $\theta = 0$ or an irregularly shaped, longitudinally skewed crack. Observation of the angular extent of the flaw region on the inspection record tends to support the former.

The fourth and fifth traces are signal indications observed in examining

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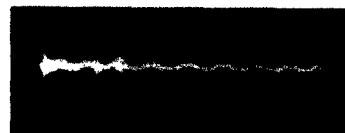
a) $\theta = 357^\circ$, $r = 1"$



b) $\theta = 9^\circ$, $r = 3"$



c) $\theta = 22^\circ$, $r = 1"$



d) $\theta = 163^\circ$, $r = 4"$



e) $\theta = 281^\circ$, $r = 1"$

Figure 20 - INDICATIONS RECEIVED AT RAM END OF MODEL BILLET CONTAINER

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other flaw regions displayed on the record. These indications are similar to the others and also are suggestive of relatively deep radial extent of the cracks.

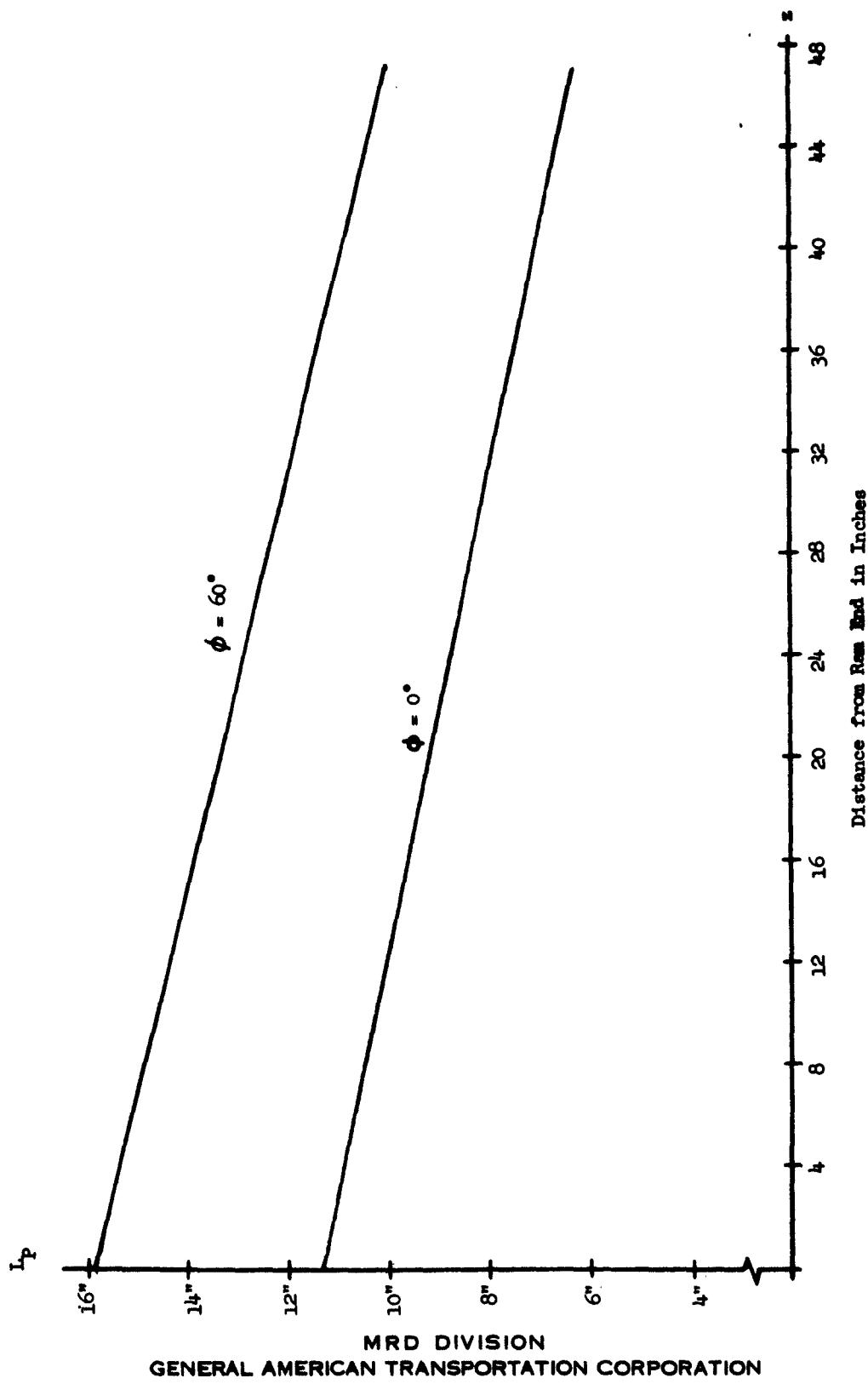
In obtaining the record discussed, mechanical variables as well as test conditions were experimented with before obtaining usable results that could be correlated. The test conditions that were varied included the inspection frequency, instrument sensitivity, and settings of gate initiation and duration. The gate setting is determined by the distance traveled by the pulse from the transducer to a crack at the bore surface. This distance is given by

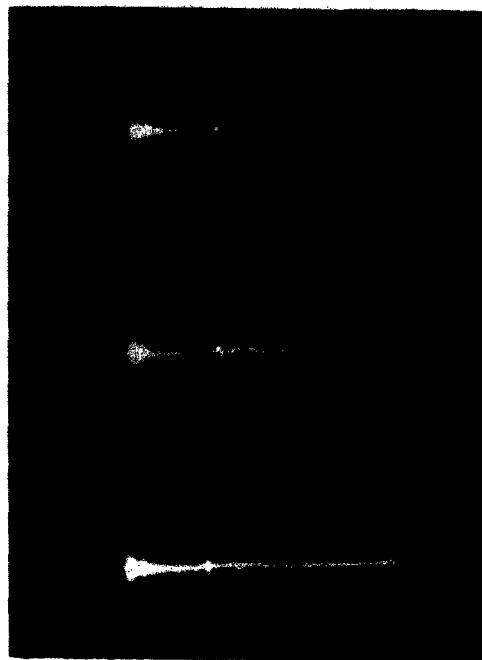
$$L_p = D_I \left[\frac{\sin(\beta/2)}{\sin \phi} \right] \quad 4.)$$

and, if the gating system is to exclude all other reflected pulses, the gate should be set to this distance. However, the taper of the shrink interface on the model billet container causes L_p to change during scanning and the gate must be sufficiently wide to accommodate the change. The value of L_p as a function of distance from the ram end is plotted in Figure 21. Scanning in the model billet container is limited to about 20 inches from the ram end and from the plot, it can be seen that L_p thus changes by about two inches in a typical scan. Figure 22 is an oscillogram of peak indications obtained from a crack at $\theta = 180^\circ$ for three values of z . The pulse is seen to lie within the duration of the gate but it can be observed that for higher values of z , the pulse travel time is lessened in accordance with expectations.

The oscillograms were obtained at a test frequency of 2.25 Megacycles with the gate initiation at ten inches and duration of six inches. Under these conditions, it can be seen that the pulse travel distances of about 12 inches in the oscillograms is inconsistent with that predicted by equation 4,

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$\theta = 270^\circ, z = 12''$

$\theta = 270^\circ, z = 14''$

$\theta = 270^\circ, z = 16''$

Figure 22 - PULSE TRAVEL TIME VARIATION IN MODEL BILLET CONTAINER

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and by such an amount that errors in velocity calibrations cannot be the cause.

One possible explanation is the occurrence of mode conversion when the shear wave pulse strikes the shrink interface. Though remaining in pure shear when angle beam methods are used in inspection of flat blocks or tubing from the O.D., the ratio of bore to shrink interface diameter determines whether the pulse remains in pure shear as the ratio determines the angle at which the pulse strikes the reflecting interface. This angle is given by the relationship

$$\psi = \arcsin \left[\left(\frac{D_B}{D_I} \right) \sin \phi \right] \quad 5.)$$

If the shrink interfaces ultrasonically appear as effectively an air-steel interface, then for values of ψ in excess of approximately 35 degrees, the reflected wave remains in pure shear. At lesser values of ψ , both a longitudinal and a shear wave may occur giving rise to the simultaneous occurrence of two inspecting waves and result in signal indication redundancy. The longitudinal wave would be reflected as an angle lesser than that of the incident shear wave as shown in Figure 23.

The magnitude of the reflected shear wave is a function of Poisson's ratio as well as the incident angle and the relationship is seen in Figure 23. If the shear wave amplitude is diminished, the longitudinal wave component is increased, and using a value of Poisson's ratio of .28, it can be seen that for ψ between 27 and 33 degrees, most of the reflected energy will be in the longitudinal mode since the reflected shear wave amplitude is nearly zero.

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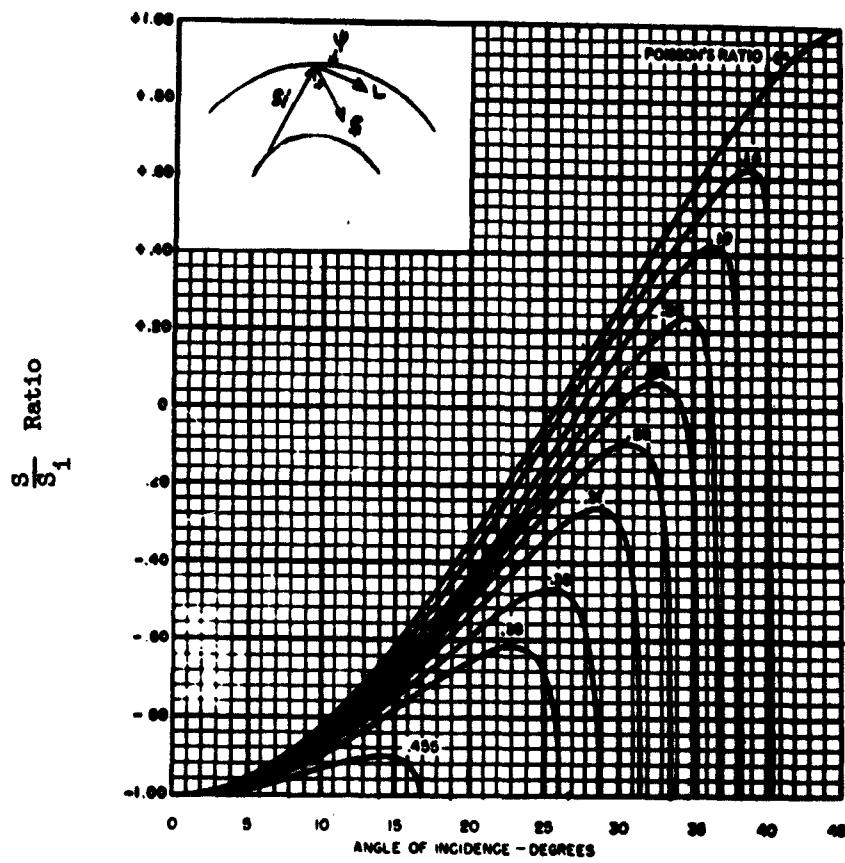


Figure 23 - SHEAR WAVE REFLECTION CHARACTERISTICS

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This second wave will never reach the bore surface, however, it is capable of being reflected back to the transducer if a radial crack is sufficiently deep. In addition, since the velocity of propagation is greater in this mode, echo pulses will be observed at a shorter distance than the instrument settings are calibrated. In addition, beam spread will cause the signal to be observed over a wider range of angular positions than for the desired reflection.

Observations are consistent with these expectations and application of equation 5 shows that ψ varies from 28.9° to 30.9° over the usable range of model billet container, which according to Figure 23, places it in the range where the effect is most pronounced for values of Poisson's ratio applicable to liner materials.

This is in no way detrimental to inspection with the system, rather it may serve to an advantage in further determining liner crack depth, by running a second scan with the gate set to record this occurrence. However, a change in inspection angle is required for designs with thick liners and small bores. In these cases, to detect with the desired shear wave technique, the loss in indication amplitude due to the pulse traveling a greater path length and the mode conversion may not permit detection.

This phenomena remains yet as conjecture and subject to further investigation, however, it appears as the most plausible explanation. This is particularly evident by observation of the recordings of Figure 24 which shows the effect of changing the gate position. Note that most crack infor-

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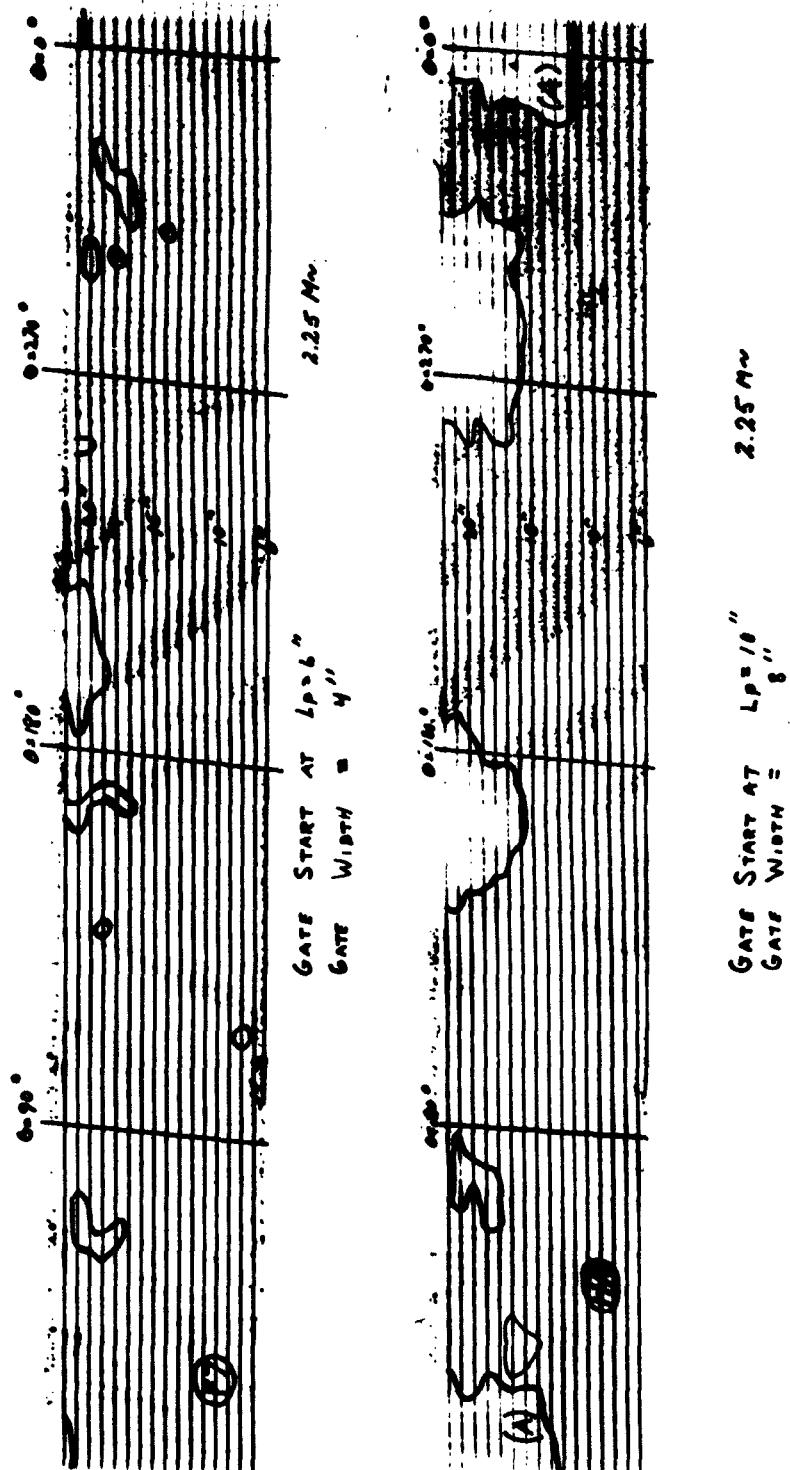


Figure 24 EFFECT OF GATE SETTING ON INSPECTION RECORDS

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mation is obtained under the condition where it would not be anticipated. Present difficulties are in resolving the numerous crack indications, many occurring simultaneously, than in obtaining them. This is particularly true when considering that the 3° taper of the shrink interface causes a 1-1/2" longitudinal offset in returning a pulse to the transducer.

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Section 3

FUTURE ACTIVITY

Continued efforts in the Development and Fabrication Phase will be confined to three major areas. The first area is that of obtaining background data through tests on the model billet container through continued use of the system discussed. This will consist of further manual inspection to confirm crack locations and correlating them to inspection records. In addition, attention will be paid towards determining crack resolution. Subsequently, tests will be conducted and reliability statistically determined for large numbers of repeated scans.

The second area will involve the development of a usable wheel search unit made of a suitable high temperature material. Silicone rubber samples will be evaluated for use in the high temperature coupler together with couplants and means for couplant application. A conventional wheel search unit will be used for determination of usability at room temperature and the scan head will be modified to accommodate it. If necessary the scanning system will be changed provided initial test results warrant this consideration. Attention then will be directed towards the use of the silicone rubber tire in subsequent system tests at elevated temperatures.

Both of the above areas are directed towards entering the third or Field Test phase of the program. This involves testing with operational assemblies and because of the variety of designs, certain designs will be selected and schedules will be made to ensure testing of particular assemblies.

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<p>AD M&D Division General American Transportation Corporation Niles, Illinois</p> <p>ASDR-7-915(IV) CONTAINER FAILURE DETECTION SYSTEM Interim Technical Engineering Report No. 4, 1 October, 1962 to 28 February, 1963 by A. B. Wiesorek and M. B. Levine March, 1963, 56 P., incl. illus. Contract AF 33(657)-7461, Proj. 7-915 Unclassified</p> <p>A prototype system has been fabricated and tested with a model billet container. Records produced by the system during the tests indicate a high degree of capability and reliability in detecting longitudinally oriented cracks.</p>	<p>UNCLASSIFIED</p> <ol style="list-style-type: none"> 1) Nondestructive Testing 2) Magnetic Testing 3) Ultrasonic Testing 4) Extrusion <p>I Levine, M. B. II General American Transportation Corporation Contract AF 33(657)-7461, Proj. 7-915 Unclassified</p> <p>A prototype system has been fabricated and tested with a model billet container. Records produced by the system during the tests indicate a high degree of capability and reliability in detecting longitudinally oriented cracks.</p>	<p>AD M&D Division General American Transportation Corporation Niles, Illinois</p> <p>ASDR-7-915(IV) CONTAINER FAILURE DETECTION SYSTEM Interim Technical Engineering Report No. 4, 1 October, 1962 to 28 February, 1963 by A. B. Wiesorek and M. B. Levine March, 1963, 56 P., incl. illus. Contract AF 33(657)-7461, Proj. 7-915 Unclassified</p> <p>A prototype system has been fabricated and tested with a model billet container. Records produced by the system during the tests indicate a high degree of capability and reliability in detecting longitudinally oriented cracks.</p>
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